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Assessment of Field Hazards to Birds from Methiocarb Applications to Fruit Crops

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Abstract: Methiocarb, a broad-spectrum carbamate insecticide, has shown efficacy in repelling birds from a variety of crops, especially fruit. To evaluate the hazards posed to wildlife, we reviewed laboratory studies of methiocarb toxicity and repellency to birds and mammals and field studies of methiocarb treatments to fruit and sweet corn. Calculations revealed that birds encountering typical maximum residue levels found in treated crops would have to eat extremely large amounts of treated food to die and would in almost all cases be repelled or immobilized long before a lethal dose could be ingested.

Results from feeding tests in laboratories support these calculations, as do the findings from 33 field studies in 28 locations. In spite of extensive searches and observations, only 14 dead birds were found in treated fields. Based on estimates from 26 studies, treated plantings averaged 15% loss of fruit to birds compared with 36% for nearby untreated plantings. We conclude that methiocarb, applied to fruit crops at 1·7 kg a.i. ha^{-1}, will not adversely affect birds.

1 INTRODUCTION

Migratory birds, most of which are federally protected, cause substantial damage to ripening fruit crops in the United States,[1–3] and elsewhere. Propane exploders, electronic noise makers, kite-hawk models, and other scaring techniques may provide limited protection for short periods, but birds usually habituate rapidly to such non-lethal frightening devices.[4,5] Reduction of populations is not a legal option in most cases, although growers sometimes resort to illegally shooting or poisoning birds out of frustration (Dolbeer, R. A., pers. observ.).[2]

Since 1970 particular attention has been focused on methiocarb (3,5-dimethyl-4-(methylthio)phenyl methylcarbamate; CAS# 2032-65-7), a broad-spectrum carbamate pesticide that has shown efficacy in repelling birds from a variety of crops.[6,7] Numerous tests have demonstrated its effectiveness for reducing bird depredations to ripening cherries,[8–10] blueberries,[11–13] and grapes.[14,15]

A formulation containing 75% methiocarb (a.i.) ('Mesurol'[R] 75% WP; Miles, Inc. (formerly Mobay Corporation)) was federally registered in the United

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States for use as a bird repellent on cherries in 1978 and blueberries in 1983. In 1986 the US Environmental Protection Agency (EPA) reduced the residue tolerance limits for methiocarb on cherries and blueberries from 25 mg kg^{-1} to 5 mg kg^{-1} and lowered the allowable application rate of this product from 2·2 kg a.i. ha^{-1} to 1·7 kg a.i. ha^{-1}.[16] Furthermore, EPA requested additional data to maintain the registration of this product for these crops. Because of these restrictions and additional costs, Miles, Inc. voluntarily withdrew registrations for blueberries in 1988 and cherries in 1989.

One of EPA's major data requests was that replicated, large-scale field studies be undertaken to determine the hazards of methiocarb applications to wildlife, especially birds [specifically data requirements 71-5 (actual field testing for mammals and birds) and 70-1 (special test, avian repellency)].[16] Before undertaking such expensive studies, we contended that the existing, diverse literature should be examined to determine if sufficient data already existed for assessing the hazards of methiocarb applications. Thus, our primary objective was to evaluate the existing literature regarding hazards to wildlife from methiocarb applications. A secondary objective was to summarize the data from field studies on the amount of damage birds inflict on fruit crops in methiocarb-treated and nearby untreated, control fields. These measures of bird damage provide an index to bird numbers and feeding levels in fruit plantings in the study areas (control fields) and to the effectiveness of methiocarb in reducing damage in treated fields. The report is divided into two sections: a review of laboratory studies of methiocarb toxicity and repellency to birds and mammals; and a review of field studies of spray applications of methiocarb for hazards to birds and bird damage to fruit crops.

2 LABORATORY STUDIES OF METHIOCARB TOXICITY AND REPELLENCY TO BIRDS AND MAMMALS

Laboratory data available include median lethal dose (LD_{50}), median temporary immobilizing dose (TI_{50}), median lethal dietary concentration (LC_{50}) and median repellent level (R_{50}). To determine the LD_{50} and TI_{50} (each expressed as mg methiocarb kg^{-1} body weight), the usual procedure is to mix the appropriate amount of methiocarb with propylene glycol, and administer 0·175 ml of solution to each bird by gavage.[17] Temporary immobilization is defined as 'the point at which a bird lost complete control over wing and leg movements'.[18] LC_{50} tests expose animals to chemical-treated food over several days. The LC_{50} of the chemical in the diet, the concentration that kills 50% of the test population, provides an estimate of the species' susceptibility to a contaminated diet.[19] Generally, the test lasts five days, but some LC_{50} determinations have been based on longer test periods.[20] Usually, R_{50} determinations are made according to the method described by Schafer and Brunton.[21] For 18 h, groups of five individually caged birds are offered 25 seeds treated with a given concentration of methiocarb. Birds that eat 12 or fewer seeds are considered repelled. If repellency is indicated (three or more birds repelled), the initial concentration (usually 1·0% by weight [i.e., 1 g methiocarb per 99 g seed)] is decreased by one-quarter or one-half a logarithmic step and a new group of birds is tested. The procedure is repeated until none of the five birds at a given level of treatment consumes fewer than 13 seeds. R_{50} is expressed as % (w/w) of methiocarb on the food items.

2.1 Results

2.1.1 *Acute toxicity (birds)*

LD_{50} determinations for 36 species range from <2 mg kg^{-1} for budgerigars to 1 000 mg kg^{-1} for ring-necked pheasants (Table 1, see Appendix 1 for scientific names of birds and mammals). Nineteen of the 36 species had LD_{50} values of 5–15 mg kg^{-1}.

2.1.2 *Repellency (birds)*

R_{50} data are available for 22 species, as are TI_{50} estimates for 16 species (Table 1). The ratio of LD_{50} to TI_{50} varies from 1·0 (house finch) to 5·6–5·7 (common grackle, European starling). This ratio, referred to as the 'safety factor',[18] provides a means to compare among species the relative risk of ingesting a lethal amount of methiocarb. It is assumed that species at greatest relative risk are those whose TI_{50} values are near the LD_{50} values.

An alternative means of assessing relative hazard is the 'hazard factor',[22] obtained by dividing the R_{50} by the LD_{50}, with the R_{50} expressed in mg kg^{-1} diet, instead of as a percentage. This procedure can lead to anomalous results,[22,23] however, and will not, therefore, be used in this report.

2.1.3 *Dietary intake to induce mortality (birds)*

A more satisfying approach to the problem of evaluating hazards of methiocarb is to determine if a bird, feeding at a normal or maximum rate on food containing methiocarb, can ingest an LD_{50} dose[24] or, more conservatively, one-fifth of an LD_{50} dose[25] before feeding ceases due to immobilization or satiation. Examples illustrating this approach with four bird species and several food items are given below and summarized in Table 2. Residues of 10 mg kg^{-1} are assumed in each case, being the maximum reported in field trials of grapes sprayed with 5·6 kg ha^{-1} methiocarb.[26] Also, up to three successive field applications of methiocarb at 0·9–1·4 kg ha^{-1} on cherries resulted in maximum residues of 9·5 mg kg^{-1}.[27,28] The upper 95% confidence limits for methiocarb residues on cherries (10 studies)

TABLE 1
Median Lethal (LD_{50}), Temporary Immobilizing (TI_{50}) and Repellent (R_{50}) Doses of Methiocarb to Birds.[a]

Species[b]	LD_{50} (mg kg^{-1})	TI_{50} (mg kg^{-1})	R_{50} (%)	*Reference*
Mallard	13·0	4·2	—	18
Japanese quail	9·5 (8·6–10·6)	—	—	20
Ring-necked pheasant	56–1000	—	0·42 (0·32–0·56)	21
California quail	24·0	—	0·56 (0·25–1·26)	21
Northern bobwhite	19·6–24·0	—	>1·0	22, 56
Sandhill crane	23·7	—	—	22
Ring-billed gull	7·5	3·0	—	17, 56
Rock dove	13·0–18·0, 11·9 (7·0–20·2)	2·4–6·0	0·15 (0·10–0·24)	17, 18, 57
Inca dove	4·2	—	—	56
White-winged dove	10·0 (5·6–18·0)	—	—	56
Eared dove	3·2	—	—	22
Mourning dove	10·0 (5·6–18·0)	—	<0·50	22, 56
Budgerigar	1·3	—	—	22
Rose-ringed parakeet	9·1 (2·6–18·8)	—	0·18 (0·12–0·26)	57
Horned lark	4·2, 31·4 (20·4–48·4)	—	—	22, 58
American crow	7·5–8·0	4·0	—	17, 56
American robin	7·5	—	—	59
Cedar waxwing	5·6	—	0·01	22
European starling	11·3–50·0	2·0	0·29	17, 22
Lark bunting	2·0	1·0	—	17
Golden-crowned sparrow	3·2	—	—	22
White-crowned sparrow	4·2	—	—	22
Red-winged blackbird	4·7–12·6	1·0	0·09 (0·05–0·16)	17, 21, 22
Tricolored blackbird	5·6 (4·0–7·8)	—	0·02 (0·01–0·04)	21
Brown-headed cowbird	7·5 (4·2–13·3)	3·0	0·32 (0·15–0·66)	17, 21
Common grackle	10·0 (5·6–18·0)	1·8	0·06 (0·02–0·18)	18, 21
Boat-tailed grackle	4·2	—	—	56
Yellow-headed blackbird	3·2	1·0 (1·8–5·6)	—	18, 56
House finch	2·4–3·0	2·4–3·0	—	17, 18
House sparrow	18·0, 14·1 (10·0–32·0) (8·7–23·1)	4·2	0·04, 0·11 (0·01–0·16) (0·06–0·18)	18, 21
Golden sparrow	5·6 (3·3–9·5)	2·7 (2·1–3·7)	0·18 (0·08–0·42)	60
Red billed quelea	4·2	-	0·02 (0·01–0·02)	61, 62
Village weaver	7·5 (2·9–19·2)	5·1 (3·1–8·5)	0·06 (0·04–0·10)	60

TABLE 1—*continued*

Species[b]	*LD_{50} ($mg\ kg^{-1}$)*	*TI_{50} ($mg\ kg^{-1}$)*	*R_{50} (%)*	*Reference*
Masked weaver	4·9 (3·1–7·6)	1·8 (1·3–2·5)	0·08 (0·03–0·20)	60
Red bishop	7·5 (4·4–12·9)	3·9 (3·0–4·9)	0·13 (0·08–0·23)	60
Chestnut mannikin	—	—	0·04 (0·03–0·07)	63
White-bellied munia	—	—	0·04 (0·03–0·05)	63
White-backed munia	3·5 (2·2–5·8)	—	0·05 (0·03–0·09)	57
Nutmeg mannikin	—	—	0·06 (0·04–0·09)	63

[a] If available, 95% confidence interval is given in parentheses below the mean.
[b] See Appendix 1 for scientific names.

TABLE 2
Calculated Feeding Times and Consumption Amounts Needed to Induce Immobilization (TI_{50}) and Mortality (LD_{50}, 1/5 LD_{50}) for Four Species of Birds Eating Various Food Items

Bird species[b]	*Food item*	*Mean wt per item (mg)*	*Mean wt of methiocarb per item*[c] *(mg)*	*Consumption necessary to: Induce mortality-LD_{50}*[a] *(Induce Temp. immobilization-TI_{50})*				*Maximum feeding rate (No. items/ minute)*	*No. of minutes feeding at maximum rate to induce*		
				Total			*LD_{50}*		*TI_{50}*	*LD_{50}*	*1/5 LD_{50}*
				No. of items	*Wt of items (g)*	*% of birds body wt.*	*(mg)*				
Starling (wt· = 90 g)	Grapes	1800[d]	0·018	57 (10)	102 (18)	113 (20)	1·02 (0·18)	0·064[e]	156	890	178
House finch (wt· = 21 g)	Grapes	1800[d]	0·018	2·8 (2·8)	5·0 (5·0)	24 (24)	0·04 (0·05)	0·011[f]	252	252	50
	Proso millet	6[g]	0·00006	840 (840)	5·0 (5·0)	24 (24)	0·05 (0·05)	12·3[c]	68	68	14
	Safflower seed	40[c]	0·0004	126 (126)	5·0 (5·0)	24 (24)	0·05 (0·05)	1[g]	126	126	25
Robin (wt· = 80 g)	Grapes	1800[d]	0·018	33	60	75	0·60	0·048[h]		687	137
Redwing (wt· = 65 g)	Rice seed	20[i]	0·0002	1530 (325)	30·6 (6·5)	47 (10)	0·306 (0·065)	30	10·8	51·0	10·2
	Insect	100[i]	0·001	306 (65)	30·6 (6·5)	47 (10)	0·306 (0·065)	15·8[j]	4·1	19·4	3·9

[a] Divide values by 5 to obtain estimates for 1/5 LD_{50}.
[b] Bird weights from Dunning;[64] see Appendix 1 for scientific names.
[c] Assuming residues of 10 $mg\ kg^{-1}$.
[d] Mean value for Zinfandel and Ruby Cabernet varieties (Tobin, M. E., unpublished).
[e] Based on mean feeding rate of 7·7 grapes per 2-h period (Tobin, M. E., unpublished).
[f] Based on mean feeding rate of 1·4 grapes per 2-h period (Tobin, M. E., unpublished).
[g] Avery[34,65] plus unpublished data.
[h] Based on mean feeding rate of 14·6 grapes per 5-h period (Tobin, M. E., unpublished).
[i] Avery, M. L. (unpublished).
[j] Orians.[31]

and blueberries (four studies) immediately after spraying at 1·7–2·2 kg ha^{-1} were 4·55 and 8·14 mg kg^{-1}, respectively.[29]

2.1.3.1 European starling. This species is a major feeder on fruit plantings. Tobin[30] (plus Tobin, M. E., unpublished) found, in a cage test, that food-deprived starlings consumed an average of 7·0 g of grapes (nearly four grapes) per hour. Assuming a methiocarb residue level of 10 mg kg^{-1} on the grapes, a starling would have to consume 102 g of grapes (*c.*57 grapes), requiring over 14 h of feeding at the rate of 7·0 g h^{-1}, to obtain an LD_{50} dose (Table 2). Even if the starling could maintain this feeding rate, the bird would become temporarily immobilized after about 2·5 h of feeding and stop eating well before reaching the LD_{50} dose. Thus, a starling has virtually no chance of consuming an LD_{50} dose (or even one-fifth of an LD_{50} dose) of methiocarb from eating grapes with 10 mg kg^{-1} residue levels.

2.1.3.2 House finch. The house finch is one of the most sensitive species to methiocarb ($LD_{50} = TI_{50} =$ 2·4 mg kg^{-1}). Using computations as above, a house finch would have to consume 5·0 g of methiocarb-treated grapes (25% of body weight), requiring 4·2 h of feeding at the calculated maximum consumption rate, to obtain an LD_{50} dose (Table 2). This calculation assumes that a finch consumes the entire fruit, thereby ingesting all the applied chemical. In fact, finches feed by puncturing the skin of the fruit and eating the pulp, thus avoiding most of the sprayed surface. It would therefore take much longer than 4·2 h to obtain the LD_{50} dose, making it unlikely that this sensitive species would ever reach even one-fifth of the LD_{50} dose.

Consumption values for house finches eating proso millet seeds and safflower seeds at maximum feeding rates also suggest that finches would be unlikely to obtain an LD_{50} dose or even one-fifth of an LD_{50} dose of methiocarb under field conditions of 10 mg kg^{-1} residue. For example, a finch would have to eat 168 proso millet seeds, requiring 13·7 min of feeding at the maximum measured rate of 12·3 seeds min^{-1}, to obtain one-fifth of an LD_{50} dose (Table 2). The maximum observed feeding bout on millet seed was 3·3 min for house finches (Avery, M. L., unpublished).

2.1.3.3 American robin. The robin, another important consumer of fruit, also appears unlikely to obtain an LD_{50} or one-fifth LD_{50} dose of methiocarb under field conditions. A robin would need to consume about 33 grapes (with 10 mg kg^{-1} residue), requiring 11·5 h of feeding at the measured rate of 2·9 grapes h^{-1}, to reach the LD_{50} value. This would require the robin to consume 75% of its body weight in grapes (Table 2). TI_{50} values have not been measured for robins.

2.1.3.4 Red-winged blackbird. This species, although not a major fruit-eater, commonly consumes seeds and insects that might be contaminated with methiocarb in a sprayed orchard. One example of each type of food is provided (Table 2). In flight-pen experiments, food-deprived male redwings consumed an average of 30 20-mg rice grains per minute (Avery, M. L., unpublished). Thus, a 65-g redwing, consuming 30 rice seeds min^{-1} with 10 mg kg^{-1} methiocarb residue, would have to consume 306 seeds (9·4% of body weight) over a 10·2-min period to consume one-fifth of an LD_{50} dose.

For redwings foraging on insects, feeding rates of 15·8 prey min^{-1} have been obtained.[31] If we assume an average prey size of 0·1 g (equivalent to a large mealworm) and compute as above, a 65-g redwing would have to feed at the rate of 15·9 prey min^{-1} for 3·9 min in order to obtain one-fifth of an LD_{50} dose of methiocarb. Such a sustained high rate of feeding is unlikely.

Methiocarb is a noncumulative, reversible cholinesterase inhibitor, making the ingestion of a lethal dose by birds even less likely than indicated above. When residue levels are low and long feeding bouts are required to achieve LD_{50} values, birds in laboratory tests have survived consumption of multiple LD_{50} doses per day.[20] In addition, the repellent nature of methiocarb to birds assures that feeding rates on treated food will typically decline rapidly, reducing the intake of methiocarb well below the rates presented above.[20,26]

2.1.4 Feeding trials using methiocarb-treated fruit (birds)

Another approach to evaluate the potential hazards to birds from methiocarb applications is by laboratory studies where birds have been offered fruit treated with methiocarb. Table 3 summarizes studies in which a total of 345 birds was exposed to grapes treated at 13–278 mg kg^{-1} methiocarb over 2·5- to 25-h periods covering 1–6 days. The only mortality was among house finches (five out of 122 birds) and four of these occurred under severe conditions (5-h tests with no alternative, untreated food available). Tobin and DeHaven[32] indicated that these deaths may have occurred through starvation because 'the finches refused to eat treated grapes.'

2.1.5 Subacute toxicity and environmental hazard (birds)

A limited amount of information has been developed on the median lethal dietary concentration (LC_{50}) of methiocarb. Published LC_{50} values for birds (all >600 mg kg^{-1}, Table 4) indicate a low risk of consuming a lethal dose, particularly in the field where residue levels on treated food should be less than 1/60 of the typical LC_{50} values and alternative, uncontaminated food is available. EPA generally considers residues below one-fifth of the LC_{50} to provide 'an ample margin of safety for a typical species'.[25] Using the categories of Hill and Comardes[19] for 5-day subacute dietary LC_{50}s,

TABLE 3
Mortality of Birds in Laboratory Tests in which the Birds were Offered Methiocarb-Treated Grapes

Species[a]	*Number exposed to methiocarb*	*Conc. of methiocarb on fruit* ($mg\ kg^{-1}$)[b]	*Time of exposure*			*Alternative food available*	*No. of birds dying*	*Reference*
			h day^{-1}	*No. of days*	*Total h*			
AR	65	20– 80	5	5	25	No[c]	0	32[d]
ES	81	50–278	5	5	25	No[c]	0	32[d]
HF	82	13– 80	5	5	25	No[c]	4	32[d]
HF	40	23	2	6	12	Yes[e]	1	66[d]
ES	40	125	2	6	12	Yes[e]	0	30[d]
GW	37	34	2·5	1	2·5	No, Yes[f]	0	67

[a] See Appendix 1.
[b] Grams of methiocarb litre^{-1} of solution converted to mg kg^{-1} residues on grapes using regression equation in Tobin and DeHaven.[24]
[c] Birds were not food-deprived before each 5-h test.
[d] Plus Tobin, M. E., unpublished.
[e] Birds were food-deprived for 12 h before each 2-h test.
[f] No alternative food available for first 0·5 h, alternative food available for remaining 2 h.

TABLE 4
Median Lethal Dietary Dose (LC_{50}) of Methiocarb for Five Bird Species

Species[a]	*Duration of test (days)*	*Dietary LC_{50}* ($mg\ kg^{-1}$)	*95% confidence limits*	*Reference*
Mallard	5	4113	2817– 7504	68
	5	1071	808– 1405	68
	5	7469	2976–10600	33
Japanese quail	5	1342	1048– 1719	19
	28	>1000	—	20
Ring-necked pheasant	5	>5000	—	68
Northern bobwhite	5	827	310– 1442	33
Mourning dove	30	630	480– 830	20

[a] See Appendix 1 for scientific names.

methiocarb is moderately toxic to northern bobwhite, slightly toxic to mallard and Japanese quail, and practically nontoxic to the ring-necked pheasant.

One means of evaluating the relative environmental hazard associated with pesticide applications involves comparing the LC_{50} to the median concentration shown to elicit food avoidance (FAC_{50}). This concept is analogous to the safety factor[18] or hazard factor,[22] but it has greater intuitive appeal for evaluating environmental effects because it is based on the birds' behavioral response to treated and untreated food rather than determined by doses administered by gavage. With methiocarb, Kononen *et al.*[33] obtained avoidance indices (LC_{50}/FAC_{50}) of 51·5 and 8·7 for the mallard and northern bobwhite, respectively, indicating a high margin of safety for the chemical with each species.

2.1.6 *Effects on reproduction (birds)*

Three studies bear on the effects of methiocarb exposure on reproduction of birds. Schafer *et al.*[20] exposed Japanese quail to dietary concentrations of 100, 316, and 1000 mg kg^{-1} methiocarb for 28 days. Egg production was depressed in the 1000 mg kg^{-1} group, and the proportion of chicks surviving 10 days was reduced at the 316 and 1000 mg kg^{-1} levels. However, direct effects of the chemical were not separated from those due to decreased food consumption and it is possible that this was responsible for these adverse effects.

In a two-year cage study of house finch feeding behavior and reproduction,[34] pairs of birds were repeatedly exposed to various types of seeds treated with methiocarb at rates from 500 to 4000 mg kg^{-1}. As part of this project, several house finch pairs were exposed to treated seeds during 5- to 10-day trials in the early stages of the nesting cycle (nest building, egg laying, and incubation). The mean numbers of nestlings and fledglings produced by adults exposed to treated seeds early in the next cycle were 3·6 and 2·1, respectively ($n = 8$ nests). These are virtually identical to those produced by untreated adult finches (3·6 and 2·0, respectively; $n = 7$ nests). Field studies of house finches in California have yielded values of 3·0 and 2·1 for numbers of nestlings and fledglings, respectively.[35,36]

Schafer *et al.*[37] fed methiocarb-treated blueberries, with residues of 50 mg kg^{-1}, to four American robin, 10 European starling, and five common grackle nestlings. No birds experienced adverse effects, and the authors concluded that nestling mortality would not occur even if nestlings were fed an exclusive diet of treated berries by their parents in the field. Based on the data from these studies, we conclude that dietary exposure to repellent doses of methiocarb is unlikely to adversely affect avian reproduction.

2.1.7 Methiocarb toxicity and repellency (mammals)

Mammalian toxicity and repellency data for methiocarb are scarce. The LD_{50} is 130–135 mg kg^{-1} for Norway rats[21] and 40 mg kg^{-1} for guinea pigs.[38] Median repellent concentrations (R_{50}) have been obtained for house mice (0·12%), California voles (0·025%), and deer mice (0·37%) (Schafer, E. W., unpublished).[39] Ten fox squirrels survived an 18-day trial during which their only food was corn treated with 0·5% (5000 mg kg^{-1}) methiocarb.[39] These are concentration levels of methiocarb 100 to 1000 times higher than would be found in sprayed orchards. In earlier tests, the same squirrels displayed preferences for untreated corn and dog food over methiocarb-treated corn.[39] Black-tailed prairie dogs developed conditioned aversions to wheat and oats treated with 0·2% methiocarb.[40] Zurcher *et al.*[41] offered corn treated with 0·5% methiocarb to thirteen-lined ground squirrels in choice and no-choice tests. When untreated food was available, squirrels avoided treated corn. Despite an average weight loss of 54%, the squirrels survived an 18-day trial with only treated (5000 mg methiocarb kg^{-1}) corn available.

These results provide no evidence of a potential environmental hazard to mammals from methiocarb, but the small number of species tested precludes a general statement of no effect.

2.1.8 Conclusions (laboratory studies)

The dietary LC_{50} test and various other free-feeding cage tests provide a more realistic basis for evaluating potential hazards in the field than does acute toxicity testing because exposure is likely to be through subacute residues on foods rather than single acute doses. An assessment methodology that incorporates the behavioral responses of the animal to treated and untreated food[33] is essential for the objective environmental hazard evaluation of a chemical such as methiocarb that operates through aversive conditioning. Acute toxicity testing does not account for the animal's behavior when confronted with treated food.

This review of toxicity and repellency data provides no support for the assumption that avian species will be adversely affected by field applications of methiocarb on fruit crops. Calculations reveal that birds encountering typical maximum residue levels found in the field would have to eat unrealistically large amounts of treated foods to die and should be repelled or immobilized long before a lethal dose could be ingested. Under laboratory conditions, even sensitive species such as house finches avoid consuming lethal amounts of methiocarb in tests where untreated food is available. Mortality during cage trials generally has occurred when only treated food with high residue levels was presented and then only minimal mortality was observed. Birds in the field seldom, if ever, encounter such high residue levels or no-choice situations.

3 FIELD STUDIES OF SPRAY APPLICATIONS OF METHIOCARB IN FRUIT AND OTHER CROPS

The literature was searched for studies that have evaluated methiocarb for reducing bird damage to cherries, blueberries and grapes and for any studies of methiocarb sprays in other ripening crops in which extensive monitoring of birds was done. Each publication was reviewed to determine the number of treated fields, area treated, application rates, types and extent of observations and searches made for birds, extent of bird activity and damage, and numbers of affected birds and other wildlife. Although observations and searches were designed to monitor bird populations, we assumed that any dead or behaviorally affected mammals noted would have been recorded.

Because study protocols varied extensively, a few explanations are given to summarize the methods used. Most studies used 'Mesurol' 75% WP and in most cases the weight of methiocarb per unit area per application was reported and converted to kg ha^{-1}. In a few studies, application rate was presented as amount of methiocarb per volume of water 'sprayed to drip'. This was converted to kg ha^{-1} based on Stickley and Ingram.[42]

All values presented regarding effort expended to observe birds relate only to treated fields from the time of the initial application of methiocarb to the final damage assessment or harvest. Preapplication observations and effort expended in control (untreated) fields are not presented. Most studies used control fields.

Two general approaches were used to monitor birds

TABLE 5
Summary of Reported Avian Hazards in Field Studies of Methiocarb Applied to Cherries as a Repellent to Reduce Bird Damage

Location	Year	No. of treated fields	Total ha treated	Chemical application (a.i.)			Bird observations and searches in treated fields				Fruit loss-birds (%)		Bird casualties			Dominant bird species[a]	Ref.
				kg ha^{-1}	No. of appli.	Total	Min. of observ.	No. of transects	No. birds recorded	No. field entries for dam. assess.	Control fields	Treated fields	Fields w/dead birds	Total dead birds	Total behav. affected birds		
MI	1971	2	0·2	6·7[b]	1–2	6·7–13·4		31	58	2	49	18	0	0	0	AR, CG	9, 69
WA	1971	2	<0·1	1·0–10·9[b]	1	1·0–3·0	[c]		412	2	6–45	3–12	0	0	0	HF, ES	70
MI	1972	1	0·2	2.2[b]	1	2·2	1020		2609	2	55	32	0	0	0	AR, RG	71
MI	1973	13	2·9	3·0	1	3·0	2355		32	13	4	5	0	0	0	AR, CW	42
MI	1976	8	16·1	2·2	2	4·4		94[d]	344	8[e]	6	6	0	0[f]	1	ES, AR	45
CA	1978	6	9·4	2·2	1	2·2		48[g,h]	23444	6	4	1	0	0	0	AR, CW, HF	8, 10
WA	1978	6	8·4	2·2	1	2·2		108[g]	10707	6	3	<1	0	0	0	HF, AR, ES	8, 72
N.Z.	1979	1	0·4	2·2–3·4[b]	2–3	4·5–10·1	[c]		[c]	1	80	10	0	0	4	CM, ST, EB	46
U.K.	1980	1	2·6	2·1	3	6·4		20[i]	2935[j]	71[k]			1	14[l]	3	EB	44
NY	1986	9	3·4	1·7	1	1·7	210	18	155	7	18	9	0	0	0	ES, AR	24
NY	1987	7	4.0	1·7[m]	1	1·7	315[n]	27	372	6	9	7	0	0[o]	0	ES, AR	43
Totals		56	47.7				3900	346	41068	124	25	10	1	14	5		

[a] See Appendix 1
[b] Estimated from information in report.
[c] Bird observations and searches were made but no details given.
[d] Each transect covered 10 to 33% of orchard.
[e] Each field was also completely searched for dead birds at time of damage assessment.
[f] Three dead birds were found in untreated, control orchard, probably the result of shooting.
[g] Each transect covered 25% of orchard.
[h] In addition, 1396 monitoring checks were made for 12 birds with transmitters.
[i] Each transect covered entire orchard.
[j] Birds captured in mist nets and banded.
[k] Field entries made for mist netting.
[l] Four of the 14 birds contained residues of methiocarb.
[m] Overall rate was 0·8 kg ha^{-1} because only 50% of rows were treated.
[n] Eighteen transects covered 7 to 20% of orchard: six transects covered 100% of orchard.
[o] One dead starling was found in untreated, control orchard.

TABLE 6

Summary of Reported Avian Hazards in Field Studies of Methiocarb Applied to Blueberries as a Repellent to Reduce Bird Damage

Location	Year	No. of treated fields	Total ha treated	Chemical application (a.i.)			Bird observations and searches in treated fields				Fruit loss-birds (%)		Bird casualties			Dominant bird species[a]	Ref.
				kg ha⁻¹	No. of appli.	Total	Min. of observ.	No. of transects	No. birds recorded	No. field entries for dam. assess.	Control fields	Treated fields	Fields w/dead birds	Total dead birds	Total behav. affected birds		
MI	1972	1	0·6	1.5	1	1·5	1 365		208	2	44	17	0	0	0	AR, ES, GC	13
NH	1972	3	4·7	3·4	1	3·4	840	14	91	6	55	35	0	0	0	AR, ES	11
IL	1973	1	<0·1[b]	2·2[c]	1–2	2·2–4·4			>50	17	61	35	0	0	0	AR, NM	73
MI	1973	6	0·5	2·2	1	2·2	4800		662	6	10	7	0	0	0	AR, ES, CG	74
Can.	1973	1	0·4	2·2	1	2·2	4 400			9	30	15	0	0	1[d]	AR	75
ME	1974	2	0·3	1·1–2·2	1	1·1–2·2	4 560		2264	2	16	18–22	0	0	0	ES, AR	76
Can.	1975	1	<0·1	2·2	2	4·4	[e]		[e]	0	58	15	0	0	0	AR	49
MI	1977	3	4·0	1·0–2·1	1	1·0–2·0	450	3	470	3	14	8	0	0	7[f]	AR, ES	48
MI	1977	2	2·5	2·1	1	2·1	480	2[g]	1742	2	14	5	0	0	5[h]	ES, AR, CG	47
CT	1980–81	6	2·5	2·1	1–2	2·1–4·2	885		47	8	51	23	0	0	0	NM, AR, NO	77
N.Z.	1980	1	<0·1	0·7	5	3·4	[e]		[e]	5	>90	<1	0	0	0	EB, CM, ST	78
N.Z.	1981	1	<0·1	0·6–0·8	8	4·8				8			0	0	0		79
CT	1982–83	12	2·4	2·2	1	2·2	[e]		[e]	12	40	30	0	0	0	NM, NO, AR	12
N.Z.	1982–84	3	0·1	0·6–1·2	5–6	2·8–6·7	[i]		[e]	18	96	43	0	0	0	CM, EB, ST	80
Totals		43	18·2				17 820	17	5534	98	45	20	0	0	13		

[a] See Appendix 1.
[b] Twenty bushes.
[c] Sprayed to drip with 0·6 kg methiocarb/500 litre water.
[d] American robin.
[e] Bird observations were not quantified but berry loss to birds in control area was high (>40%), indicating high bird pressure.
[f] Five American robins, two northern orioles; may have resulted from malathion application to field.
[g] During each transect, 100% of each field was searched.
[h] Northern orioles; may have resulted from malathion application to field.
[i] 'Bird observations were made several times at each site using hides at dawn.'

TABLE 7

Summary of Reported Avian Hazards in Field Studies of Methiocarb Applied to Grapes as a Repellent to Reduce Bird Damage

Location	Year	No. of treated fields	Total ha treated	Chemical application (a.i.)			Bird observations and searches in treated fields				Fruit loss-birds (%)		Bird casualties			Dominant bird species[a]	Ref.
				kg ha^{-1}	No. of appli.	Total	Min. of observ.	No. of transects	No. birds recorded	No. field entries for dam. assess.	Control fields	Treated fields	Fields w/dead birds	Total dead birds	Total behav. affected birds		
NH	1971	1	<0·1	5·6	2	11·2	[b]		[c]	4	[c]		0	0	0	AR, ES	81
CA	1974–76	3	1·5	3·8	2	7·6	>1380	90	>225	3	45	11	0	0	0	HF, ES	50, 82
Austral.	1977–78	4	[d]	1·9	1	1·9	480	[e]	[c]	4	[c]		0	0	0	EB, GS	14
CA	1978	12	9·0	2·1–4·2	1–3	2·4–7·4	370	70[f]	801	12	[g]		0	0	5[h]	HF, CQ	15, 83
NY	1978	9	?	2·2	1–3	2·2–6·7	[i]			9	28–51[j]	3–7[j]	0	0	0		53
OH	1978	5	2·6	2·8	1–2	2·8–5·6	1104		464	7	15	2	0	0	0	AR, ES	52
OR	1978	8	4·0	2·2	2	4·4	800	>64[k]	261	8	[l]		0	0	5[h]	AR	15, 84
CA	1979	11	3·2	2·0–2·9	2–3	4·5–6·7	590	85[m]	550	11	[n]		0	0	0	HF, AR	51
Totals		53	>20·4				4724	309	2 301	58	33	9	0	0	10		

[a] See Appendix 1.
[b] Bird observations were made but no details were provided.
[c] Yield reduced by over 50% in untreated rows, indicating heavy bird pressure, but no bird numbers presented.
[d] Outer three rows treated on one side of each field.
[e] 'One of us ... searched for dead birds for about one hour per week during February and March.'
[f] Twenty-six transects each covering >10% of the rows in a field searching for dead birds, 44 transects counting birds.
[g] Untreated fields had 1·8 times more damage than treated fields.
[h] Two American robins, two western bluebirds and one house finch in California, five American robins in Oregon; all recovered.
[i] 'Not one related bird mortality was observed, despite extensive monitoring.'
[j] Damage was estimated in two treated and two untreated vineyards.
[k] Twelve to 30% of each treated vineyard searched at least twice a week for at least four weeks.
[l] Untreated fields had 3·6 times more damage than treated fields.
[m] Twenty-six transects each covering >10% of the rows in a field searching for dead birds, 59 transects counting birds.
[n] Untreated fields had 1·2 times more damage than treated fields.

in treated fields. Many studies used stationary counts in which an observer spent a fixed amount of time at a certain location in or at the edge of each field recording the number and species of birds entering, exiting or present. Other studies used transect counts in which an observer walked a certain route through each orchard or field and recorded the birds observed. If stationary counts were used and the time spent making observations per field was recorded, then the total time spent in observations was calculated. For transect counts, the total number of transects per study was calculated, but the time spent walking was not usually presented and could not be calculated. In calculating the number of transects walked, each coverage of a field was counted as one transect even if several passes were made through the orchard or field.

The total field entries to assess damage were also calculated for each study. We assumed that any dead or affected birds or other wildlife observed during these field entries would have been noted and reported in the results. Thus, these field entries give another measure of effort expended to monitor wildlife populations in treated fields. The amount of fruit loss to birds, when available, was also used as an index of bird activity in the fields.

3.1 Results

3.1.1 Field tests in cherries

Eleven field studies were conducted between 1971 and 1987 in 56 orchards totaling 47·7 ha treated with methiocarb. These studies were in nine locations in four US states and two other countries (Table 5). Application rates ranged from 1·7 to 6·7 kg a.i. ha^{-1} with one to three applications per orchard. Nine of the 11 studies used an application rate >1.7 kg a.i. ha^{-1}, the rate which was registered in the US for blueberries and cherries.

At least 65 h were spent observing the treated orchards for birds. In addition, at least 346 transects were walked through the orchards to observe birds. Each transect covered 7–100% of a treated orchard. Also, at least 124 orchard entries were made to assess damage or operate mist nets (Table 5).

Studies in California,[8] Washington,[8] New York,[43] the United Kingdom,[44] and Michigan,[45] were the most thorough in searching for dead and behaviorally affected birds. In California and Washington, 48 and 108 transects, respectively, were walked, each covering 25–100% of a treated orchard. In California, 1396 monitoring checks also were made for 12 birds with radio transmitters attached.[10] In Michigan,[45] 94 transects, each covering 10–33% of a treated orchard, were walked. In addition, each of the eight orchards was completely searched for dead and affected birds at the time of damage assessment. In New York,[43] 18 transects, each covering 7–20% of a treated orchard, were walked. In addition, each of the six orchards was completely searched once for dead and affected birds. In the UK, mist netting was conducted on 71 days after spray application to monitor bird activity. In addition, 20 systematic searches were made of the treated orchard, 163 nest boxes and 74 natural nests were monitored in the orchard, and systematic live-trapping of mammals was conducted (Table 5).

Over 41 000 birds were recorded in the 11 studies with American robins and European starlings being most numerous. Bird activity was high in most tests; the 10 studies in which damage was estimated averaged 25% loss of cherries to birds in control orchards compared with 10% loss in treated orchards.

A total of 18 dead birds was found in these studies, 14 in the treated orchard in the UK where a total of 6·4 kg methiocarb ha^{-1} was applied and four in control orchards in New York[43] and Michigan.[45] Only four of the 14 dead birds in the treated orchard in the UK had residues of methiocarb.[44] Searches were not made in a control orchard in the UK study. Eight behaviorally affected birds were noted, four in New Zealand[46] where total applications rates of up to 10·1 kg methiocarb ha^{-1} and harvest residues of 18 mg kg^{-1} were reported, one in Michigan[45] where a total application rate of 4·5 kg ha^{-1} was made, and three in the UK study[44] (Table 5). In the UK study, nesting activity and nesting success in the orchard were found to be typical for the various species monitored.

3.1.2 Field tests in blueberries

A total of 14 field studies was conducted between 1972 and 1984 in 43 plantings totalling 18·2 ha treated with methiocarb. These studies were in 12 locations in five US states and two other countries (Table 6). Methiocarb application rates ranged from 0·6 to 3·4 kg ha^{-1} with one to eight applications per planting. Eight of the 14 studies used an application rate >1.7 kg methiocarb ha^{-1}, and 11 of the 14 studies averaged >1.7 kg ha^{-1} when multiple applications were considered.

At least 297 h were spent observing treated fields for birds. In addition, 17 transects were walked through the plantings, each covering up to 100% of the planting. Also, at least 98 field entries were made to assess damage (Table 6).

American robins and European starlings were the most numerous species among the 5534 birds recorded in the 14 studies. Bird activity was generally high; the 13 studies that measured loss of berries to birds averaged 45% loss in control and 20% loss in treated plantings. However, no dead birds or other dead wildlife were found in any treated plantings. Three studies recorded behaviorally affected birds, 12 from two studies in southwestern Michigan[47,48] and one in New Brunswick, Canada.[49] In the Michigan studies, the insecticide malathion was mixed with 'Mesurol' at the time of application and may have contributed to the temporary abnormal behavior.

3.1.3 Field tests in grapes

Eight field studies were conducted between 1971 and 1979 in 53 vineyards totalling more than 20 ha treated with methiocarb. These studies were in seven locations in five US states and one other country. Application rates ranged from 1·9 to 3·8 kg ha^{-1} with one to three applications per vineyard. All eight studies used an application rate > 1.7 kg methiocarb ha^{-1} (Table 7).

A minimum of 78·7 h was spent observing treated vineyards for birds and over 309 transects were walked, each covering > 10% of a treated vineyard. Also, at least 58 entries were made in treated vineyards to assess damage. Three studies in California[15,50,51] and one in Oregon[15] provided the most extensive searches for dead or affected birds (Table 7). For example, in the Oregon test, 12–31% of each treated vineyard was searched at least twice per week for at least four weeks after methiocarb application.

Among the 2301 birds recorded in the eight studies, American robins, house finches, and European starlings were the most numerous species. The three studies[50,52,53] that measured loss of grapes to birds averaged 33% loss in control and 9% loss in treated vineyards. No dead birds or other dead wildlife were found associated with treated vineyards. Ten behaviorally affected birds, five each in Oregon and California, were noted in treated vineyards where methiocarb was applied at 2·1–3·6 kg ha^{-1}; all recovered within 4 h of their discovery.[15]

3.1.4 Field tests in sweet corn

Extensive observations for dead or behaviorally affected birds were made in two studies in Ohio in 1976 and 1978 that evaluated spray applications of methiocarb to repel red-winged blackbirds from ripening sweet corn.[54,55] In all, 12 1·6 ha fields were treated with one to three applications of methiocarb at 1·7 kg ha^{-1}. Over 14 h of bird observations were made in treated fields. In addition, 12 transects, each covering 5–10% of the corn rows were walked through the fields, and over 80 field entries were made to monitor insect numbers and measure bird damage. No sick or dead birds were noted. Bird activity was high; control fields averaged 28% of the corn ears damaged by birds compared with 11% of the ears damaged in nearby treated fields.

3.1.5 Conclusions (Field tests in fruit crops)

From 1971 to 1987, 33 studies at 28 locations in 10 US states and four other countries have evaluated spray applications of methiocarb to reduce bird damage to cherries, blueberries and grapes. These studies used 152 treated plantings totalling more than 86 ha; 127 of the 152 plantings had > 1.7 kg methiocarb applied per ha.

These studies totalled over 440 h of observations for birds in treated fields. At least 672 transects, each covering 7–100% of a treated area, were walked and over 280 entries were made into these treated areas to assess the damage done by birds or to monitor mist nets. One study used radio telemetry to monitor 12 birds in and around a treated orchard and another used mist nets and nest boxes to monitor bird populations. Over 48 000 birds representing more than 40 species were recorded during the transects and observations. Bird activity was generally high in the study areas. Based on estimates of fruit loss to birds in 26 studies, overall treated plantings lost an average of 15% of the fruit to birds compared with 36% for nearby control plantings.

Only one of the studies,[44] in which one 2·6-ha cherry orchard was extensively monitored, recorded any mortality to birds or other wildlife in a methiocarb-treated area. It is important to note that in this study no control orchards were monitored to determine if similar levels of mortality would have been recorded in untreated areas subjected to the same intensive monitoring. Two other studies recorded dead birds in control fields. A total of 28 birds was noted in seven studies whose temporarily aberrant behaviour may have been caused by ingestion of methiocarb-treated fruit. Although the studies varied in the degree to which observations and searches were made for dead and affected birds, the aggregate results indicate that the impact of methiocarb applications in fruit crops was negligible. Evaluations of methiocarb applications in ripening sweet corn where bird activity was high also revealed no hazards.

4 GENERAL CONCLUSIONS

The review of methiocarb toxicity and repellency data from laboratory studies provides no support for the assumption that birds will be adversely affected by field applications of methiocarb on fruit crops. The findings from a review of 33 field studies of methiocarb use in fruit crops at 28 locations are consistent with the findings from the laboratory studies. Only one of the field studies recorded any mortality to birds in a methiocarb-treated planting. Two studies recorded dead bird(s) in control plantings. We conclude that methiocarb, applied to fruit crops at 1·7 kg (a.i.) ha^{-1}, will not adversely affect birds.

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APPENDIX 1 Scientific names of birds and mammal species mentioned in text and tables. Abbreviations are given for species listed in Tables 3, 5–7.

Bird species:

Abbrev.	*Common name*	*Scientific name*
	American crow	*Corvus brachyrhynchos* (Brehm)
AR	American robin	*Turdus migratorius* (L.)
	Boat-tailed grackle	*Quiscalus major* (Vieillet)
	Brown-headed cowbird	*Molothrus ater* (Boddaert)
	Budgerigar	*Melopsittacus undulatus* (Shaw)
CQ	California quail	*Callipepla californica* (Shaw)
CW	Cedar waxwing	*Bombycilla cedrorum* (Vieillot)
	Chestnut mannikin	*Lonchura malacca* (L.)
CG	Common grackle	*Quiscalus quiscula* (L.)
CM	Common mynah	*Acridotheres tristis* (L.)
	Eared dove	*Zenaida auriculata* (Bonaparte)
EB	Eurasian blackbird	*Turdus merula* L.
ES	European starling	*Sturnus vulgaris* L.

Abbrev.	*Common name*	*Scientific name*
GW	Gray-backed white-eye	*Zosterops lateralis* (Latham)
GC	Gray catbird	*Dumetella carolinensis* (L.)
	Golden-crowned sparrow	*Zonotrichia atricapilla* (Gmelin)
	Golden sparrow	*Passer luteus* (Lichtenstein)
	Horned lark	*Eremophila alpestris* (L.)
HF	House finch	*Carpodacus mexicanus* (Muller)
	House sparrow	*Passer domesticus* (L.)
	Inca dove	*Columbina inca* (Lesson)
	Japanese quail	*Coturnix japonica* (Temminck and Schlegel)
	Lark bunting	*Calamospiza melanocorys* (Stejneger)
	Mallard	*Anas platyrhynchos* L.
	Masked weaver	*Ploceus taeniopterus* (Reichenbach)
	Mourning dove	*Zenaida macroura* (L.)
	Northern bobwhite	*Colinus virginianus* (L.)
NM	Northern mockingbird	*Mimus polyglottos* (L.)
NO	Northern oriole	*Icterus galbula* (L.)
	Nutmeg mannikin	*Lonchura punctulata* (L.)
	Red-billed quelea	*Quelea quelea* (L.)
	Red bishop	*Euplectes orix* (L.)
	Red-winged blackbird	*Agelaius phoeniceus* (L.)
	Ring-billed gull	*Larus delawarensis* (Ord)
	Ring-necked pheasant	*Phasianus colchicus* L.
	Rock dove	*Columba livia* Gmelin
RG	Rose-breasted grosbeak	*Pheucticus ludovicianus* (L.)
	Rose-ringed parakeet	*Psittacula krameri* (Scopoli)
	Sandhill crane	*Grus canadensis* (L.)
ST	Song thrush	*Turdus philomelos* Brehm
	Tricolored blackbird	*Agelaius tricolor* (Audubon)
	Village weaver	*Ploceus cucullatus* (Miller)
WB	Western bluebird	*Sialia mexicana* (Swainson)
	White-backed munia	*Lonchura striata* (L.)
	White-bellied munia	*Lonchura leucogastra* (Parkes)
	White-crowned sparrow	*Zonotrichia leucophrys* (Forster)
	White-winged dove	*Zenaida asiatica* (L.)
	Yellow-headed blackbird	*Xanthocephalus xanthocephalus* (Bonaparte)
Mammal species:		
	Black-tailed prairie dog	*Cynomys ludovicianus* (Ord)
	California vole	*Microtus californicus* (Peale)
	Deer mouse	*Peromyscus maniculatus* (Wagner)
	Fox squirrel	*Sciurus niger* L.
	Guinea pig	*Cavia cobaya* L.
	House mouse	*Mus musculus* L.
	Norway rat	*Rattus norvegicus* (Berkenhout)
	Thirteen-lined ground squirrel	*Spermophilus tridecemlineatus* (Mitchill)